Examining the relation between mood and rumination in remitted depressed individuals: A dynamic systems analysis

Ernst H.W. Koster [1,2*], Lin Fang [1], Igor Marchetti [1], Ulrich Ebner-Priemer[3], Peter Kirsch [4], Silke Huffziger[5] and Christine Kuehner [5]

[1] Ghent University, Belgium

[2] La Sapienza University of Rome, Italy

[3]Chair of Applied Psychology, Karlsruhe Institute of Technology, Germany

[4]Department of Clinical Psychology, Central Institute of Mental Health, Medical Faculty Mannheim/ Heidelberg University, Germany

[5]Research Group Longitudinal and Intervention Research, Department of Psychiatry and Psychotherapy, Central Institute of Mental Health, Medical Faculty Mannheim/ Heidelberg University, Germany

* Corresponding author

Ernst Koster

Department of Psychology and Educational Sciences

Psychopathology and Affective Neuroscience Lab

Henri Dunantlaan 2

B-9000 Ghent

Belgium

E-mail: Ernst.koster@ugent.be

Abstract

Cognitive theories of recurrent depression suggest that the relationship between mood and cognition is altered by previous depressive episodes. In individuals remitted from depression (RMD) this would be linked to a larger susceptibility for new depressive symptoms. This study explored whether the association between mood and rumination indeed is different between RMD and non-depressed controls relying on dynamic systems theory (DST). From DST we selected entropy, defined here as the level of unpredictability in the relation between mood and rumination, as main variable of interest. Daily electronic dairy measures of mood and rumination were administered in 31 RMD patients and 32 healthy controls. The results indicate that mean levels of rumination and negative mood were elevated in RMD compared with controls. At the group level, entropy did not differ significantly and entropy was also not associated with the number of episodes. However, entropy predicted depressive symptoms in the RMD group and the brooding subtype of rumination in both groups at six months follow-up. These data are specific for entropy and were not obtained using mean levels of momentary mood and rumination.

Keywords: depression; rumination; remission; dynamic systems; entropy

Negative mood and self-reflective thought are tightly coupled (Moberly & Watkins, 2010). Provided that negative mood is thought to signal a discrepancy between actual state and desired state (Carver & Scheier, 1998), negative mood elicits self-reflection to understand the causes of such discrepancy (Watkins, 2008). In addition, there is extensive evidence that excessive levels of self-reflection in the form of rumination, which is oftentimes defined as "attending to the causes and consequences of negative affect" (Nolen-Hoeksema, 2001, p. 546), can lead to heightened levels of negative affect (Mor & Winquist, 2002). The reciprocal relation between negative mood and rumination can explain why rumination is one of the key cognitive vulnerability factors in the onset and maintenance of depression (Nolen-Hoeksema, Lyobomrisky, & Wisco, 2008).

For many patients, depression is a recurrent disorder with data indicating high chances of new depressive episodes, even after initial remission from a first depressive episode (Kessing, Hansen, Andersen & Angst, 2004; Monroe & Harkness, 2005). In this context it is important to understand the mechanisms that are associated with elevated risk of recurrent episodes. Despite the key role assigned to rumination in first episodes of depression, much less is known about the phenomenology of rumination in remission from depression and its relation to recurrence of depression. Theories of recurrent depression have argued that the experience of depressive episodes can influence the link between mood and depressogenic cognition (Teasdale & Barnard, 1993). For instance, in the differential activation hypothesis (Teasdale & Barnard, 1993) it is argued that the link between negative mood and negative cognition (in the form of dysfunctional attitudes) is strengthened by having experienced one or more depressive episodes. Specifically, in individuals who have remitted from depression (RMD), negative mood reactivates negative cognition much more strongly compared with never depressed individuals. This concept is referred to as *cognitive reactivity* and there indeed is some empirical support for this notion (Segal, et al., 2006) although there are also notable failures to observe this effect (Van Rijsbergen et al., 2013).

Interestingly, there is a paucity of research examining whether the *interplay* between mood and rumination is altered in function of previous depressive episodes. Such alteration would be conceivable as oftentimes RMD patients suffer from negative consequences of the previous depressive episode (at the social or socio-economic levels; e.g., job loss) that could give rise to rumination. Moreover, it could be that rumination is more maladaptive and more easily triggers negative mood in RMD patients compared with individuals with no prior history of depression. Importantly, in conceptualizing this relationship, previous depressive episodes are not necessarily linked to linear increases in the association between rumination and negative mood. It may also be that the relationship between negative mood and rumination becomes characterized by more *variability* in both constructs and lower levels of *predictability*. This could for instance be observed because of active attempts to suppress depressive thoughts which can be successful under low cognitive load but can backfire under more demanding and stressful conditions (Rude et al., 2002). Based on cognitive reactivity theory of depression one would hypothesize that the link between rumination and mood becomes tighter in RMD patients. Alternatively, it could be that the link between rumination and mood is more disrupted and less organized in RMD patients.

In order to understand the relation between rumination and negative mood we applied a dynamic systems framework to specifically examine their interplay. Dynamic systems theory (DST) posits that a dynamic system shows features that are absent or non-detectable at the level of components that make up the system. Moreover, a dynamic system is supposed to unfold over time in a non-linear fashion, whereby each part interacts with the other(s) determining the behavior of the whole system. Given its features, DST is useful to model and analyze in real time the complex interaction between mood and rumination.

In the DST framework many possible indexes can be examined. We selected *entropy* as main index. Entropy, originated from thermodynamics (Rudolf, 1865) and information theory (Shannon & Weaver, 1949), has been widely used in informatics, biology and recently in psychology to describe the unpredictability of a system (Carhart-Harris et al., 2014; Hollenstein, 2013; Hirsh, Mar, & Peterson, 2012). The level of entropy represents the level of randomness or (un)predictability about the state of a dynamic system, with higher levels of entropy indicating a more unpredictable system. In psychopathology theories, this concept is increasingly used to allow understanding of uncertainty associated with the outcome of conflicting perception and behavior, for example, in the context of the experience of anxiety (Hirsh et al., 2012). In the present study, we use a specific type of entropy, visit entropy, which refers to the predictability of transition between different states that an individual reports with regard to dimension of mood and rumination. Here higher levels of visit entropy reflect frequent and unpredictable changes in the interplay between momentary rumination and mood changes, whereas lower levels of visit entropy suggest that their fluctuations are more certain.

In our study, we investigated the relation between rumination and negative mood in RMD vs. never-depressed individuals based on electronic daily dairy assessment of both constructs. Individuals were asked to assess their momentary mood and ruminative thinking ten times a day during two consecutive days. These two daily measurements were then used as constitutive dimensions of the dynamic system where all possible joint states were presented (otherwise known as "*state space*"; see Fig 1; Lamey et al., 2004; Lewis, Lamey, & Douglas, 1999) and visit entropy was extracted to indicate the unpredictability of the transitions between different states. In addition to characterizing the nature of the relationship between rumination and mood as a function of previous depression, we also examined whether differences in the relationship between rumination and mood is predictive of new depressive symptoms after remission. For this purpose, participants in the study were examined at a first time point and reassessed on depressive symptoms six months later.

Method

Participants

Data for the present study were derived from the study by Huffziger et al. (2013), in which the participants were 31 individuals (age: M = 45.42, SD = 7.98; 22 female) with remitted major depressive episodes ranging from 1 to 10 (RMD group) and 32 healthy controls (age: M = 44.50, SD = 7.86; 22 female) with no present or past depressive disorder (CTL group). The RMD group and controls were matched on age, gender and education levels (Table 1).

Symptom- and trait measurements

Study inclusion and exclusion criteria were assessed with the Structured Clinical Interview for DSM-IV axis I disorders (SCID-I, German version Wittchen et al., 1997). Interviewer-rated depressive symptoms were assessed with the Montgomery and Asberg Depression Rating Scale (MADRS; Montgomery & Asberg, 1979). Self-rated depressive symptoms over the past two weeks were measured with a validated German version of the Beck Depression Inventory-2nd Edition (BDI-II; Beck, Steer, & Brown, 1996; German version: Hautzinger et al., 2006). The Cronbach's αs of MADRS and BDI in the present samples were high (MADRS: α =.80 for RMD group and α =.73 for CTL group; BDI-II: α =.91 for RMD group and α =.78 for CTL group.)

To measure trait rumination, participants completed two 5-item subscales of Response Styles Questionnaire (RSQ; Treynor et al., 2003; German version Huffziger & Kuehner, 2012), in which brooding is defined as a maladaptive and symptom-focused form of rumination, prospectively associated with negative mood and depression, whereas reflection is conceived as a relatively adaptive and problem-solving-focused form of rumination (Joormann, Dkane, & Gotlib, 2006; Moberly & Watkins, 2008). In a psychometric evaluation on the instrument, both subscales were found to show acceptable internal consistency, retest reliability and convergent validity (Huffziger & Kuehner, 2012). In the current sample, the Cronbach's αs of brooding scale were .83 for the RMD group and .69 for the CTL group whereas of reflection scale were .84 for the RMD group and .78 for the CTL group, indicating acceptable internal consistency.

Ambulatory assessment (AA)

After the diagnostic screening session and filling in questionnaires, participants were asked to report their momentary mood and rumination by performing the AA with ten assessments per day on two successive days. Specifically, their momentary mood was defined and evaluated with six bipolar items with three scales which have been demonstrated previously with good reliability and sensitivity to change (Wilhelm & Schoebi, 2007): valence, calmness, and energetic- arousal. Here, our interests only focused on the valence scale in which the valence of mood was assessed by rating two bipolar items ("content-discontent", "unwell-well") on a scale from 0 to 6. Scores of the "content-discontent" item were recoded, so that the total momentary valence of mood was represented from 0 to 6, in which higher scores reflect a more positive momentary mood state. According to Wilhelm and Schoebi (2007), reliability at the between-person level for valence was 0.92, and the reliability for measuring the average mood at a given day was 0.88.

In addition, participants measured their momentary rumination state by rating two items ("At the moment, I am thinking about my problems" and "At the moment, I am thinking about my feelings") on a scale from 0 (not at all) to 7 (very much) by Moberly and Watkins

(2008). The scores on these two scales were also averaged to obtain a single momentary rumination score. Although psychometric data on the validity and reliability of these items is still limited, previous research has shown that these items are suitable in an AA context (Huffziger et al., 2013; Moberly & Watkins, 2008). In the study by Huffziger et al. (2013), momentary ruminative state was moderately correlated with trait rumination and predicted mean cortisol output over the day, even if controlled for daily stressors.

State Space Grid Analysis

The state space consisting of both momentary rumination and mood was plotted and analyzed by using GridWare 1.15a (Hollenstein, 2013). In the grid, we divided the scale of momentary rumination into 16 categories and also the scale of momentary mood into 14 categories in order to provide precise detail about the rates of changes (due to the reason of using average scores, the smallest unit of changes was 0.5). Therefore, the momentary state of rumination is represented on the x-axis, ranging from 0 (no rumination) to 14 (very much rumination) and the momentary valence of mood is represented on the y-axis, ranging from 0 (negative mood) to 12 (positive mood). Each point on the grid represents a single time point where individuals provided joint information about rumination and mood. By examining the data points on the grid, we can get a time-series trajectory on different states visited by a participant (see Fig.1). In addition, the missing data were included as a new (or unknown) state on the grid (indicated as state 15 in Rumination axis and state 13 in Valence of mood axis in the state space grid).

To measure the uncertainty of the system, we used *Visit Entropy* as main index (Hollenstein, 2013). Generally, the level of entropy represents the level of randomness or (un)predictability about the state of a system. In a recent study by Sravish et al. (2013), among all measures indexing system (un)predictability as provided by GridWare 1.15a, entropy resulted to be the most informative variable. In the present study, computation of the entropy was based on the probability (P) of the visit of a single state, which was calculated by

$$P= \frac{Number\ of\ A\ visited}{Number\ of\ total\ visits} \tag{1}$$

where A denotes one certain joint state and visits represent one or more consecutive data points into a single state, beginning from the entry of a trajectory and ending with the exiting of it. Then, the combination of all the probabilities of every joint state was used to extract the *visit* entropy index of the whole system, i.e.

$$\text{Entropy} = \sum_{i=1}^{n} \left(\text{Pi} * \ln\left(\frac{1}{\text{Pi}}\right)\right) \tag{2}$$

Here the visit entropy index is formulated in such a way that higher levels of visit entropy indicate a more unpredictable transition among the occurring states of a system.

Procedure

Participants were told that they were taking part in a study on “thought and feelings” and were administered a telephone screening session. Following the prescreening, each participant was evaluated using the Structured Clinical Interview for DSM-IV axis I (SCID-I; Wittchen et al., 1997) and MADRS by a qualified clinical psychologist in an individual session. After that, participants received the AA instructions and completed the BDI-II and the two subscales of the RSQ (time 1). Then, the AA procedure followed and was carried out for 2 consecutive workdays during which participants had to rate their momentary mood and rumination state on a personal digital assistant (PDA, Palm Tungsten E2, Palm Inc.) after a beep. After six months, participants were reassessed with the BDI-II, two subscales of the RSQ, and the MADRS.

Data analytic plan

To investigate the dynamic interplay between momentary mood and rumination in RMD versus healthy controls we performed the following analyses. First, descriptive information for both groups is provided. Then, independent *t*-tests are used to test group differences in momentary rumination, mood, as well as entropy. Then, we examined the correlation between numbers of episodes and the interplay between rumination and mood. Finally, to investigate prediction of depressive symptoms and trait rumination six months later (time 2), we conducted hierarchical regression analyses (HRAs) with BDI-II, MADRS, brooding, and reflection score at time 1 in the first step and entropy in the second step as predictors and BDI-II, MADRS, brooding and reflection score at time 2 as dependent variables (separately).

Results

Group characteristics. Descriptive information about both groups can be found in Table 1. RMD group and controls did not significantly differ on age and gender, but the RMD group had a significantly higher score of BDI-II, MADRS, Brooding and Reflection.

First, differences between the two groups on mean momentary rumination levels, mood and entropy were examined. The results revealed that the RMD group (M = 1.32; SD = 1.17) had marginally significant higher levels of momentary rumination than the CTL group (M = 0.82; SD = 0.87), t (61) = 1.93, p = .058, d = .49. Moreover, the mood ratings were significantly less positive in the RMD group (M= 3.97, SD = 1.01) compared with the CTL group (M = 4.68, SD = 1.15, t (61) = 2.60, p = .01, d = .66). However, groups did not differ significantly on entropy, RMD group (M= 2.26, SD = .44), CTL group (M= 2.04, SD= .66), t < 1.7.

In a next step, the impact of previous episodes on the interaction of mood and rumination was investigated by inspecting correlations between numbers of episodes, entropy, momentary state measures in the RMD group. The results show that the number of episodes was not correlated with momentary rumination (r_s = .27, p = .15), momentary valence (r_s = -.01, p > .1), as well as entropy (r_s = .23, p > .1). In addition, we checked for a possible difference in the association between momentary rumination and mood in the RMD versus the CTL group. Fisher's Z test indicated that the difference in correlations was not statistically significant (RMD: r_s= -.61, CTL: r_s = -.75; z< 1.10, p > .1 (Preacher, 2002).

Predicting recurrent depressive symptoms. In order to examine whether alterations in the dynamic interplay between rumination and mood is of relevance for the clinical phenomenon of recurrent depression, we investigated prediction of depressive symptoms and trait rumination six months later (time 2) based on symptom- and trait scores at time1 and entropy. Separate HRAs were conducted for predicting depression and rumination scores in the RMD and CTL group where in a first step entered relevant T1 questionnaire scores (e.g., time 1 BDI-II) and included entropy in the second step to examine whether entropy has incremental predictive value. The results of the HRA on BDI-II scores at time 2 are presented in Table 2. BDI-II scores at time 1 significantly predicted BDI-II scores at time 2 in both RMD and control group. Interestingly, after controlled for BDI-II scores at time 1, entropy in the RMD group explained an additional 16% of variance of BDI-II scores at time 2. In the CTL group, no significant associations were found with entropy.

To examine whether similar effects are obtained with the interview-based clinical assessment, we performed a similar HRA using the MADRS scores. Results of this HRA are presented in Table 2. In the RMD group, MADRS scores at time 1 and entropy were found to significantly predict MADRS scores at time 2. Importantly we observed a tendency (p = .098) that entropy could explained additional variance (5%) of depressive symptoms as assessed at time 2, whereas no significant contribution of entropy was found in the CLT group.

The HRA for brooding scores at time 2 is shown in Table 3. In both groups, brooding scores at time 1 included in the first step of the HRA significantly predicted brooding scores at time 2. When entropy was added in the second step, there's a tendency that it added to the prediction of brooding in both the RMD group (i.e., 5%, p = .098) and the CTL group (i.e., 7%, p = .075). In line with the previous results, higher levels of brooding at time 1 and higher levels of entropy are related to higher levels of brooding at time 2. The results of the HRA on reflection at time 2 are presented in Table 3. In both RMD and control groups, reflection scores at time 1 were found to be significantly predictive of reflection scores at time 2. However, after entering entropy in the second step, it significantly explained additional variance (9%) of reflection scores at time 2 only in the CTL group. Note that we also conducted HRAs examining whether mean levels of daily reported rumination and negative mood had a similar predictive effect in RMD individuals and, as shown in Supplementary material (Table S2), this was not the case.

Discussion

In order to examine whether the predictability of the relation between mood and rumination changes in function of previous episodes of depression we applied dynamic systems theory and used a specific index to assess (un)predictability, that is *visit entropy*. The key findings of our study are that (1) at the group level, RMD and CTL do not have different levels of entropy; (2) entropy adds significantly to the prediction of future depressive symptoms in RMD but not in CTL individuals; (3) entropy marginally significantly predicted brooding in both groups. These findings are discussed below.

The first issue to be considered is that no significant difference between RMD patients and CTL group were found in the correlation between mood and rumination as well as in the dynamic relation of these two constructs, i.e., the levels of the entropy. Moreover, the correlation between depressive episodes and entropy was not significant within the RMD group. These findings are not in line with the idea of cognitive reactivity where one would expect a tighter link between mood and negative cognition (see Scher, Ingram, & Segal, 2005) but are in line with recent studies that failed to detect higher cognitive reactivity in RMD (Van Rijsbergen et al., 2013; Wichers, Geschwind, & Peeters, 2010). However, it should be noted that previous work on cognitive reactivity has mainly focused on dysfunctional attitudes and not rumination. However, the absence of any differences at the group level does not exclude the possibility that higher levels of entropy would heighten vulnerability for recurrent depressive symptoms. In that respect, the prospective part of the current study is of crucial importance.

A key finding of our study is that the pattern characteristics of the interplay between mood and rumination play an important role in predicting future depressive symptoms and levels of rumination. Entropy significantly predicted depressive symptoms assessed by self-report BDI-II in six months later, even when controlling for depressive symptoms at time 1. Moreover, clinical assessment with the MADRS interview confirmed this result (although here the effect was only a trend). It is noteworthy that we also conducted regression analyses examining whether mean levels of daily reported rumination and negative mood had a similar predictive effect and, as shown in Supplementary material (Table S2), this was not the case. Thus, these results suggest that entropy, the level of unpredictability between mood and rumination, plays a specific role as vulnerability factor.

This notion that higher levels of entropy are associated with maladaptive outcomes is further substantiated by the finding that in both groups, entropy marginally significantly predicted brooding (but not reflection) which is considered the more depressogenic type of rumination (cf. Treynor et al., 2003). Although these effects are rather small it is noteworthy that these effects emerged while controlling for brooding where rumination is considered a rather stable trait (Nolen-Hoeksema, 2001), which thus is quite a stringent test to test for incremental predictive validity of entropy. Here it would be interesting to examine multiple timepoints to assess whether entropy predicts new depressive symptoms in the RMD group through mediation of brooding.

Our study integrates ambulatory assessment and the dynamic system theory in relation to psychopathology. Given the specific role of entropy in predicting future depressive symptoms, a DST framework could be used to detect and measure the subtle alterations in RMD patients' relation between mood and cognition. This implies that both at the theoretical and clinical level, instead of focusing on mean levels of rumination and mood, a more detailed analysis of the interaction between mood and cognition could be a promising way to improve our understanding of cognitive vulnerability in recurrent depression. Here, a key theoretical question is why higher levels of entropy are maladaptive and predict brooding across both groups and new depressive symptoms in the RMD group. We can speculate that more unpredictability is problematic because it could represent that sometimes individuals engage in rumination even when in a neutral or positive mood. Alternatively, thought control strategies that only occasionally work (i.e., initial suppression of negative thought leading to subsequently increases in negative thought, see Rude et al., 2002) could be another reason for heightened entropy that especially has detrimental effects in the RMD group.

Provided the novel use of DST indices in predicting depression scores, there are several issues that need further consideration in follow-up research. First, given the small sample size, only limited factors could be included as predictors of future depression symptoms and trait rumination. Thus, it is possible that with more predictors, more sophisticated hierarchical regression analyses could be applied. Second, given that the present daily assessments were conducted during a relatively short time period where participants were mostly in a neutral or positive mood state, the amount of variability observed in mood and rumination might be larger in more prolonged assessment. Third, we only compared a remitted depressed sample to a healthy control group. Although alterations in the link between affect and rumination have been proposed specifically in relation to a history of depression, we cannot exclude that similar alteration would be observed in other pathologies as well. Given the fact that ruminative responses have been shown to enhance the risk not only for depression but also for other psychological disorders including anxiety, substance abuse, and eating disorders, and has therefore been conceptualized as a transdiagnostic risk factor (Nolen-Hoeksema et al., 2008), future research should include different control groups to examine whether the current findings are depression-specific.

Which developments do we envision based on this initial research? We feel that recent advances in gathering ecologically-valid large data sets on cognition, emotion, and behavior through ecological momentary assessment allows a much more fine-grained understanding of mechanisms involved in psychopathology. As noted by others (e.g. van de Leemput et al., 2014), this type of data invites to rethink some of the traditional statistical analyses where oftentimes linear relations are assumed between risk factors and symptoms of psychopathology. In that regard, dynamic systems theory is a highly interesting framework that is particularly suitable to examine transitions. In the current paper we focused mainly on entropy but longer and more intensive assessment would allow to examine the relation between entropy and the emergence of new depressive symptoms as well as episodes in a more precise way. A second key question raised by the data on the link between affect and rumination is the causal influence between each of these constructs. Provided that in this study both constructs were measured almost simultaneously it is difficult to infer the directionality of influences between these two factors. However, when a more intensive sampling is used, future studies could examine this issue using for instance Granger causality test. Understanding the direction of influence between these factors would be highly beneficial in clarifying why higher levels of entropy in the relation between affect and rumination predicts new depressive symptoms in remitted depressed individuals.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Author Contributions

C.K. & P.K. designed the study and E.K. & I.M. developed the DST conceptualization for this study. S.H. collected the data. U.E.-P. supervised the AA assessment part of the study. E.K., L.F. & I.M. analyzed and interpreted the data. E.K. & L.F. drafted the manuscript, and I.M. & C.K. provided critical revisions. All authors approved the final version of the manuscript before submission.

Funding and acknowledgement

This research was supported by a CSC scholarship awarded to Lin Fang and by a grant from the Deutsche Forschungsgemeinschaft to Christine Kuehner (KU1464/4-1,2) and Peter Kirsch (576/12-1,2). The authors thank Tom Hollenstein for advice on analytic methodology.

References

Beck, A.T., Steer, R.A., & Brown, G.K. (1996). *Manual for the Beck Depression Inventory-II*. San Antonio, TX: Psychological Corporation.

Carhart-harris, R.L., Leech, R., Tagliazucchi, E., Hellyer, P.J., Chialvo, D.R., Feilding, A., & Nutt, D. (2014). The entropic brain: A theory of conscious states informed by neuroimaging research with psychedelic drugs. *Frontiers in Human Neuroscience*, 8-20.

Carver, C.S., & Scheier, M.F. (1998). *On the self-regulation of behavior*. New York: Cambridge University Press.

Clausius, R. (1865). *The mechanical theory of heat— with its applications to the steam engine and to physical properties of bodies*. London, England: John van Voorst.

Hautzinger, M., Keller, F., Kuehner, C., & Beck, A.T. (2006). *Das Beck Depressionsinventar II. Deutsche Bearbeitung und Handbuch zum BDI II*. Frankfurt a.M., Harcout Test Services.

Hirsh, J.B., Mar, R.A., & Peterson, J.B. (2012). Psychological entropy: A framework for understanding uncertainty-related anxiety. *Psychological Review, 119*, 304-320.

Hollenstein, T. (2013). *State Space Grids: Depicting dynamics across development*. New York: Springer.

Huffziger, S., Ebner-Priemer, U., Zamoscik, V., Reinhard, I., Kirsch, P., & Kuehner, C. (2013). Effects of mood and rumination on cortisol levels in daily life: an ambulatory assessment study in remitted depressed patients and healthy controls. *Psychoneuroendocrinology, 38*, 2258-2267.

Huffziger, S., & Kuehner, C. (2012). Die Ruminationsfacetten Brodding und Reflection. *Zeitschrift für klinische Psychologie und Psychotherapie, 41*, 38-46.

Joormann, J., Dkane, M., & Gotlib, I.H. (2006). Adaptive and maladaptive components of rumination? Diagnostic specificity and relation to depressive biases. *Behavior Therapy, 37*, 269-280.

Kessing, L.V., Hansen, M.G., Andersen, P.K., & Angst, J. (2004). The predictive effect of episodes on the risk of recurrence in depressive and bipolar disorders; a life-long perspective *.Acta Psychiatrica Scandinavica, 109*, 339-344.

Lamey, A., Hollenstein, T., Lewis, M. D., & Granic, I. (2004). GridWare (Version 1.1) [Computer software]. http:// statespacegrids.org

Lewis, M.D., Lamey, A.V., & Douglas, L. (1999). A new dynamic systems method for the analysis of early socioemotional development. *Developmental Science, 2,* 458-476.

Moberly, N.J., & Watkins, E.R. (2008). Ruminative self-focus and negative affect: An experience sampling study. *Journal of Abnormal Psychology, 117,* 314-323.

Moberly, N.J., & Watkins, E.R. (2010). Negative affect and ruminative self-focus during everyday goal pursuit. *Cognition and Emotion, 24,* 729-739.

Monroe, S.M., & Harkness, K.L. (2005). Life stress, the "kindling" hypothesis, and the recurrence of depression: considerations from a life stress perspective. *Psychological Review, 112,* 417-445.

Montgomer, S., & Asberg, M. (1979). A new depression scale designed to be sensitive to change. *British Journal of Psychiatry, 134,* 382-389.

Mor, N., & Winquist, J. (2002). Self-focused attention and negative affect: A meta-analysis. *Psychological Bulletin, 128,* 638-662.

Nolen-Hoeksema, S. (2001). Ruminative coping and adjustment to bereavement. In M. Stroebe, R.O. Hansson, W. Stroebe, & H. Schut (Eds.), *Handbook of bereavement research: Consequences, coping and care* (pp. 545-562). Washington, DC: American Psychological Association.

Nolen-Hoeksema, S., Wisco, B. E., & Lyubomirsky, S. (2008). Rethinking rumination. *Perspectives on Psychological Science, 3,* 400-424.

Preacher, K. J. (2002, May). Calculation for the test of the difference between two independent correlation coefficients [Computer software]. Available from http://quantpsy.org.

Rude, S.S., Wenzlaff, R., Gibbs, B., Vane, J., & Whitney, T. (2002). Negative interpretive biases predict subsequent depression symptoms. *Cognition and Emotion, 16,* 423-440.

Scher, C.D., Ingram, R.E., & Segal, Z.V. (2005). Cognitive reactivity and vulnerability: Empirical evaluation of construct activation and cognitive diatheses in unipolar depression. *Clinical Psychology Review, 25*, 487-510.

Segal, Z.V., Kennedy, S., Gemar, M., Hood, K., Pedersen, R., & Buis, T. (2006). Cognitive reactivity to sad mood provocation and the prediction of depressive relapse. *Archives of General Psychiatry, 63,* 749-755.

Shannon, C.E., & Weaver, W. (1949). *The mathematical theory of communication*. Urbana: University of Illinois Press.

Sravish, A. V., Tronick, E., Hollenstein, T., & Beeghly, M. (2013). Dyadic Flexibility during the Face-to-Face Still-Face Paradigm: A dynamic systems analysis of its temporal organization. *Infant Behavior and Development, 36*(3), 432-437.

Teasdale, J.D., & Barnard, P.J. (1993). *Affect, cognition and change: Re-modelling depressive thought*. Hove: Lawrence Erlbaum Associates Ltd.

Treynor, W., Gonzalez, R., & Nolen-Hoeksema, S. (2003). Rumination reconsidered: a psychometric analysis. *Cognitive Therapy Research, 27,* 247-259.

van de Leemput, I. A., Wichers, M., Cramer, A. O. J., Borsboom, D., Tuerlinckx, F., Kuppens, P., van Nes, E. H., Viechtbauer, W., Giltay, E. J., Aggen, S. H., Derom, C., Jacobs, N., Kendler, K. S., van der Maas, H. L. J., Neale, M. C., Peeters, F., Thiery, E., Zachar, P., & Scheffer, M. (2014). Critical slowing down as early warning for the onset and termination of depression. *Proceedings of the National Academy of Sciences, 111,* 87-92.

Van Rijsbergen, G.D., Bockting, C.L., Burger, H., Spinhoven, P., Koeter, MW., Ruhé, H.G., Hollon, S.D., & Schene, A.H. (2013). Mood reactivity rather than cognitive reactivity is predictive of depressive relapse: a randomized study with 5.5-year follow-up. *Journal of Consulting and Clinical Psychology, 81*, 508-517.

Watkins, E.R. (2008). Constructive and unconstructive repetitive thought. *Psychological Bulletin, 134,* 163-206.

Wichers, M., Geschwind, N., van Os, J., & Peeters, F. (2010). Scars in depression: is a conceptual shift necessary to solve the puzzle? *Psychological Medicine, 40*, 359-365.

Wilhelm, P., & Schoebi, D. (2007). Assessing mood in daily life: structural validity, sensitivity to change, and reliability of a short-scale to measure three basic dimensions of mood. *Psychological Assessment, 23*, 258-267.

Wittchen, H.U., Wunderlich, U., Gruschwitz, S., & Zaudig, M. (1997). *SCID: Structured Clinical Interview for DSM0IV Axis I Disorders*. Hogrefe, Goettingen, Germany.

Table 1

Demographic and baseline characteristics for remitted depressed patients and healthy controls

	RMD (*n*= 31)		CTL (*n*=32)			
	M (*SD*)/%	*Observed range*	*M* (*SD*)	*Observed range*	*Test statistic*	*p*
Age	45.42 (7.98)	27-54	44.50 (7.86)	26-55	t= 0.46	.647
Gender (male:female)	9:22	-	10:22	-	Chi^2= 0.04	.848
Education (% high school degree)	64.5%		62.5%		Chi^2= 0.03	.868
BDI-II	9.61 (8.27)	0-36	3.41 (3.93)	0-14	t= 3.78	< .001
MADRS	5.45 (4.90)	0-22	1.31 (2.33)	0-11	t= 4.26	< .001
N of episodes	4.13 (2.29)	1-10	-	-		
Brooding	10.87 (3.84)	5-19	8.13 (2.43)	5-13	t= 3.38	.001
Reflection	10.97 (3.67)	5-19	8.53 (3.31)	5-16	t= 2.77	.007

Note: RMD, remitted depressed group; CTL, control group; BDI-II, Beck Depression Inventory-2nd Edition; MADRS, Montgomery-Asberg Depression Rating Scale.

Table 2

Hierarchical regression analysis predicting BDI-II T2 and MADRS T2 (separately) in two groups

Steps	*Predictors*	$\Delta R2$	*df*	*B*
BDI-II				
RMD group				
Step 1		.16*	(1,29)	
	BDI-II T1			.40*
Step 2		.16*	(1,28)	
	BDI-II T1			.23
	Entropy			.43*
CTL group				
Step 1		.33**	(1,28)	
	BDI-II T1			.57**
Step 2		.03	(1,27)	
	BDI-II T1			.50**
	Entropy			.19
MADRS				
RMD group				
Step 1		.45***	(1,29)	
	MADRS T1			.67***
Step 2		.05†	(1,28)	
	MADRS T1			.56**
	Entropy			.25†
CTL group				
Step 1		.23**	(1,28)	
	MADRS T1			.48**
Step 2		.02	(1,27)	
	MADRS T1			.44*
	Entropy			.15

Note: $^{\dagger}p < .1$; $*p < .05$; $**p < .01$; $***p < .001$. RMD, remitted depressed group; CTL, control group; BDI-II, Beck Depression Inventory-2nd Edition; MADRS, Montgomery-Asberg Depression Rating Scale.

Table 3

Hierarchical regression analysis predicting brooding T2 and reflection T2 (separately) in two groups

Steps	*Predictors*	Δ*R2*	*df*	*β*
Brooding				
RMD group				
Step 1		.49***	(1,29)	
	Brooding T1			.70***
Step 2		.05†	(1,28)	
	Brooding T1			.67***
	Entropy			.22†
CTL group				
Step 1		.35**	(1,28)	
	Brooding T1			.59**
Step 2		.07†	(1,27)	
	Brooding T1			.51**
	Entropy			.28†
Reflection				
RMD group				
Step 1		.56***	(1,29)	
	Reflection T1			.75***
Step 2		.00	(1,28)	
	Reflection T1			.72***
	Entropy			.08
CTL group				
Step 1		.34**	(1,28)	
	Reflection T1			.58**
Step 2		.09*	(1,27)	
	Reflection T1			.48**
	Entropy			.32*

Note: †p< .1; **p*< .05; ***p*< .01; ****p*< .001. RMD, remitted depressed group; CTL, control group.

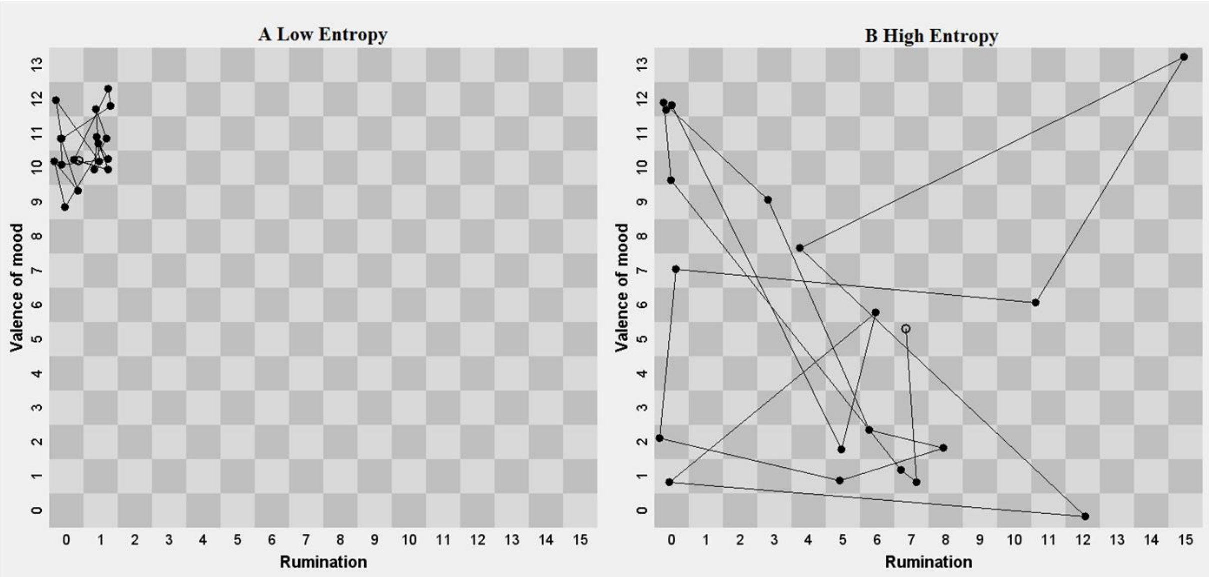

Fig.1. State space of momentary rumination and valence of mood representing (in panel A and B respectively) two individuals in this study. Panel A is characterized by lower visit entropy than Panel B. Note that score "15" on rumination and "13" on valence represent missing data.

Supplementary tables:

S1: Correlations (Spearman) between BDI-II scores, MADRS scores, brooding scores, reflection scores, momentary measurements and Entropy in RMD and CTL group

S2: Hierarchical regression analysis predicting BDI-II scores T2 and MADRS scores T2 (separately) in two groups (including BDI-II scores/ MADRS scores T1 as step 1 and mean momentary rumination and mood scores as step 2 in HRA)

S3: Hierarchical regression analysis predicting brooding T2 and reflection T2 (separately) in two groups (brooding/ reflection T1, Momentary Rumination and Momentary Mood as predictors)

Table S1

Correlations (Spearman) of BDI-II scores, MADRS scores, Brooding scores, Reflection scores, momentary measurement and Entropy (correlations above diagonal and in bold font refer to the RMD, correlations below the diagonal to the CTL)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
1.BDI-II T1		**.44***	**.73*****	**.35**†	**.48****	**.45***	**.39***	**.29**	**.59*****	**-.40***	**.47****
2.BDI-II T2	.58**		**.58****	**.84*****	**.32**†	**.64*****	**.53****	**.52****	**.58****	**-.38***	**.73*****
3.MADRS T1	.39*	.57**		**.55****	**.22**	**.27**	**.33**†	**.15**	**.54****	**-.55****	**.46****
4.MADRS T2	.38*	.75***	.62***		**.10**	**.51****	**.36***	**.45***	**.59*****	**-.46****	**.64*****
5.Brooding T1	.44*	.59**	.44*	.30		**.75*****	**.58****	**.31**†	**.19**	**.02**	**.31**†
6.Brooding T2	.27	.58**	.50**	.44*	.58**		**.62*****	**.70*****	**.41***	**-.11**	**.46***
7.Reflection T1	.40*	.31†	.24	.26	.35*	-.06		**.72*****	**.56****	**-.11**	**.47****
8.Reflection T2	.38*	.47**	.30	.28	.39*	.34†	.61***		**.54****	**-.03**	**.39***
9.Momentary Rumination	.50**	.42*	.37*	.28	.40*	.44*	.31†	.57**		**-.61*****	**.66*****
10.Momentary Mood	-.50**	-.44*	-.54**	-.37*	-.47**	-.51**	-.31†	-.36†	-.75***		**-.50****
11.Entropy	.41*	.36†	.38*	.27	.38*	.43*	.28	.48**	.92***	-.86***	

Note: †p< .1; *p< .05; **p< .01; ***p< .001. RMD, remitted depressed group; CTL, control group; BDI-II, Beck Depression Inventory-Revised; MADRS, Montgomery-Asberg Depression Rating Scale.

Table S2

Hierarchical regression analysis predicting BDI-II T2 and MADRS T2 in remitted depressed and controls

Steps	*Predictors*	$\Delta R2$	*df*	*B*
BDI-II				
RMD group				
Step 1		.16*	(1,29)	
	BDI-II T1			.40*
Step 2		.11	(2,27)	
	BDI-II T1			.08
	Momentary Rumination			.41
	Momentary Mood			-.07
CTL group				
Step 1		.33**	(1,28)	
	BDI-II T1			.57**
Step 2		.09	(2,26)	
	BDI-II T1			.41*
	Momentary Rumination			.45
	Momentary Mood			.13
MADRS				
RMD group				
Step 1		.45***	(1,29)	
	MADRS T1			.67***
Step 2		.03	(2,27)	
	MADRS T1			.53**
	Momentary Rumination			.20
	Momentary Mood			- .03
CTL group				
Step 1		.23**	(1,28)	
	MADRS T1			.48**
Step 2		.05	(2,26)	
	MADRS T1			.47*
	Momentary Rumination			.47
	Momentary Mood			.34

Note: **p*< .05; ***p*< .01; ****p*< .001. RMD, remitted depressed group; CTL, control group; BDI-II, Beck Depression Inventory-Revised; MADRS, Montgomery-Asberg Depression Rating Scale.

Table S3

Hierarchical regression analysis predicting brooding T2 and reflection T2 in remitted depressed and controls

Steps	*Predictors*	Δ*R2*	*df*	*B*
Brooding				
RMD group				
Step 1		.49***	(1,29)	
	Brooding T1			.70***
Step 2		.09	(2,27)	
	Brooding T1			.65***
	Momentary Rumination			.33*
	Momentary Mood			.06
CTL group				
Step 1		.35**	(1,28)	
	Brooding T1			.59**
Step 2		.07	(2,26)	
	Brooding T1			.45*
	Momentary Rumination			.23
	Momentary Mood			- .07
Reflection				
RMD group				
Step 1		.56***	(1,29)	
	Reflection T1			.75***
Step 2		.10*	(2,27)	
	Reflection T1			.55***
	Momentary Rumination			.47**
	Momentary Mood			.28
CTL group				
Step 1		.34**	(1,28)	
	Reflection T1			.58**
Step 2		.13	(2,26)	
	Reflection T1			.47**
	Momentary Rumination			.70*
	Momentary Mood			.42

Note: *p< .05; **p< .01; ***p< .001. RMD, remitted depressed group; CTL, control group.